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BANK BARNS COMPARED WITH ABOVEGROUND BARNS

FOR HOUSING DAIRY CATTLE

by Max J. LaRock and
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BANK BARNS COMPARED WITH ABOVEGROUND BARNS FOR HOUSING DAIRY CATTLE[1]

By MAX J. LAROCK, *Department of Agricultural Engineering, University of Wisconsin;* and ROBERT G. YECK, *Agricultural Engineering Research Branch, Agricultural Research Service, United States Department of Agriculture*

INTRODUCTION

In the past, bank barns have been criticized as being less satisfactory than aboveground barns for housing dairy cattle and for the produc- of high-quality milk. The purpose of this study was to investigate and compare conditions in the two types of barns. The results will be useful to farmers, farm-building specialists, and milk sanitarians.

FIGURE 1.—A bank barn, showing the ground-level approach to the second floor made possible by the earth bank.

[1] A report of a cooperative study conducted in Wisconsin as a regional research project by the Agricultural Experiment Station, University of Wisconsin, and the United States Department of Agriculture.

A bank barn has been defined as a barn that has earth against the greater part of one or more walls of its first floor, or stable section (fig. 1). Generally, in barns of this type more than 80 percent of one longitudinal first-floor wall and sometimes parts of the end walls are below the grade line. These barns fit into hillside construction very well, and the earth bank provides ground-level approach to the second floor.

Bank dairy barns are common in many areas of rolling topography. It is estimated that in Wisconsin alone there are between 60,000 and 70,000 bank barns.

SCOPE OF THE STUDY

The dairy-barn conditions that were investigated and compared in this study were temperature, humidity, light intensity, barn odors, and quality of milk produced.

The study was divided into two parts, as follows:

Part I.—A detailed study of temperature, humidity, light intensity, and organoleptical observations of odor in a group of 16 bank barns and 10 aboveground barns.

Part II.—A statistical comparison of the quality of milk produced in 83 bank barns and 119 aboveground barns.

Some attention was also given to the microbial content of the barn air.

In part I, temperature and humidity were considered major factors in cattle health and milk production, indicating both the thermal environment and the efficiency of the ventilating system. An efficient ventilating system aids in reducing barn odors which may be a source of off-flavors in milk. An efficient ventilating system also aids in reducing the moisture present in the barn, a factor in the life of the structure.

The influence of natural light intensity within the dairy barn on the quality of milk produced is somewhat controversial. However, light intensity was studied because it was different in the two types of barns.

In part II, milk produced in bank barns was compared with milk produced in aboveground barns to determine if any of the differences between the two types of barns caused a difference in milk quality.

For ease of identification, bank barns were assigned odd numbers, except that barn 2 was a bank barn.

Barn 1 was operated by the University of Wisconsin. All others were privately owned, and the investigations were carried out in cooperation with the owners.

DESCRIPTION OF THE TEST BARNS

The 26 barns chosen for use in making the detailed investigations in part I of this study were representative of bank barns and aboveground barns in Wisconsin. All were of two-story construction with cattle on the first floor and hay storage above. All but 3 barns had 2 rows of stanchions with the cattle facing out. A typical floor plan is shown in figure 2. Barns 11 and 13 had 2 rows of stanchions with

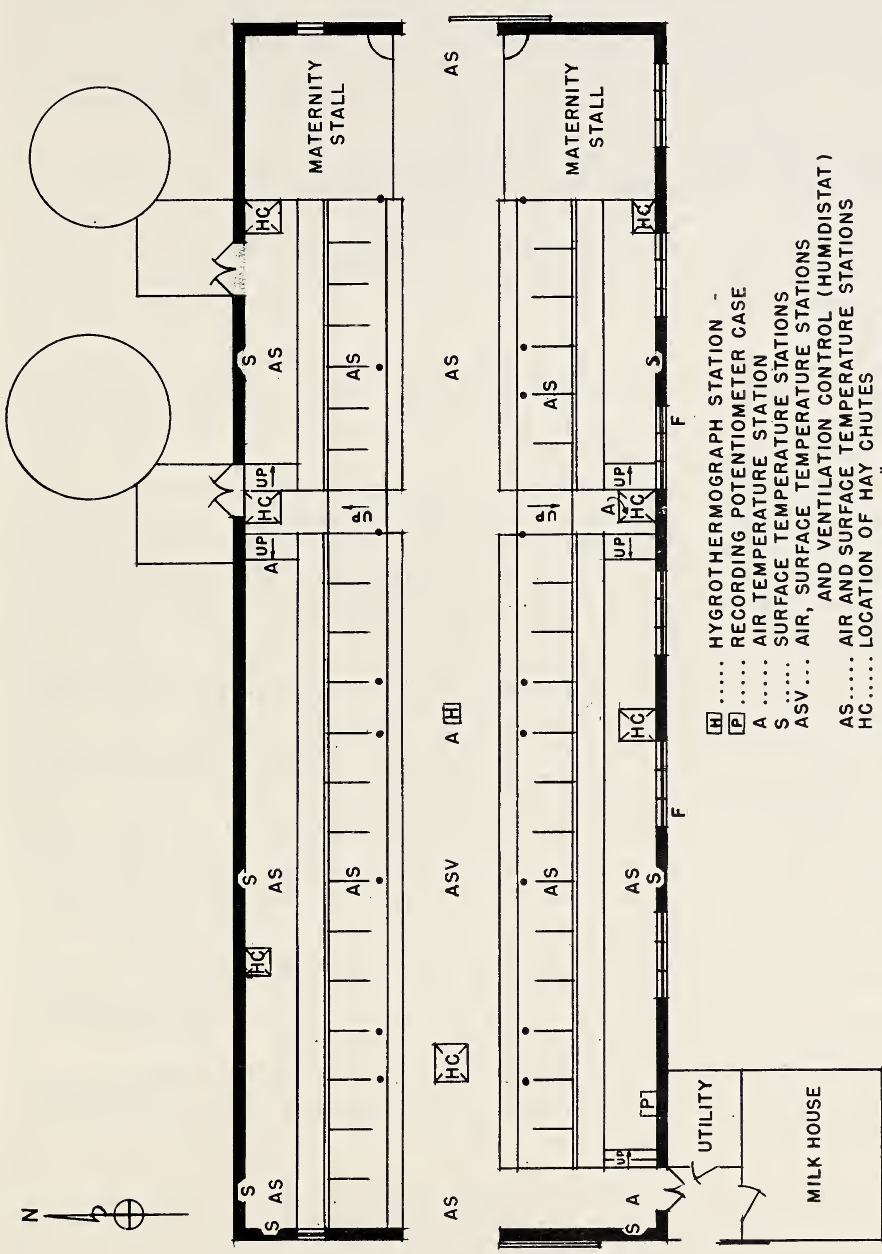

FIGURE 2.—Floor plan of bank barn 15, showing stations for measuring air temperature and surface temperature. This plan is typical of many barns that have two rows of stanchions with the cattle facing out.

the cattle facing in; barn 7 had 4 rows of stanchions across the narrow dimension of the barn.

All barns had concrete floors. Gutters ranged from 14 to 18 inches in width and were of varied depths. Mangers included sweep-in and high-back types, some with curved bottoms and some with flat bottoms.

Exposed walls were of various construction, ranging from stone 24 inches thick to single-boarded wood frame. Bank walls were either stone 24 inches thick or concrete 8 or 10 inches thick. Table 1 shows the wall construction of each barn, also the barn dimensions, window area, orientation, and cattle population.

All but three barns had mow floors of matched wood flooring above exposed joists. Bank barn 19 had a ceiling of matched lumber below the joists with no flooring above, and aboveground barns 14 and 22 had both ceilings and mow floors of matched lumber. The hay-storage space was of wood construction in all barns except barn 14. The hay-storage space in barn 14 was steel covered with galvanized-iron siding.

In all bank barns but one and in some aboveground barns, there was a driveway to the second-floor haymow. Hay or bedding, ranging from 6 inches to several feet in depth, covered most of the mow floor in each barn during the entire test.

The barn population, as shown in table 1, ranged from 16 to 60 cows in stanchions. Sometimes dry cows, the herd sire, or yearling heifers were put in the empty stanchions. The cows in barns 7 and 21 were Brown Swiss; in barn 3, Milking Shorthorns; and in all others, Holsteins. Most of the cows were in lactation. The estimated average weight of the cows was 1,300 pounds.

The number of horses in barns is also shown in table 1. In three barns the horses were sold during the test, and calves or the herd sire were put in their stalls.

The total pen area, as shown in table 1, includes the area of horse stalls. The number of 1,000-pound units in pens includes horses and represents the total weight of all animals in pens.

The method of ventilation is indicated in table 1 by the following keys: HC (hay chute) represents the opening of hay chutes and silage chutes to exhaust air from downstairs, not a recommended procedure but often used; G (gravity system) represents ventilation by a wood or steel flue; M (mechanical system) represents a motor-driven exhaust-fan system with thermostat control. Barns 13, 19, 22, 27, and 29 had intake air ports designed by the fan manufacturer. In the other barns, cracks and windows were used as air intakes.

Other supplementary information on the relationship of floor area, wall area, ceiling area, and volume to 1,000-pound units of livestock is given in table 2.

TABLE 1.—*Size, type of construction, orientation, population, pen area, and ventilating system of the 16 bank barns and 10 aboveground barns studied*

Barn No.	Size	Maximum height of ceiling		Square feet of floor area per square feet of window area	Construction [1]		Orientation [2]		Cattle in stanchions	Pen area	Thousand-pound units in pens	Horses	Ventilating system [3]
					Exposed walls	Bank wall	Long axis	Bank wall					
	Feet	*Feet*	*Inches*	*Number*					*Number*	*Square feet*	*Number*	*Number*	
BANK BARNS													
1	35 x 84	8	0	51	WF–C	S	E–W	N	26	480	4	0	M
2	42 x 62	7	10	30	WF–S	S	SW–NE	NW	30	340	8	0	HC
3	34 x 86	7	10	36	S	S	SW–NE	NW	30	320	6	2	HC
5	33 x 100	7	6	50	C	C–S	N–S	W	43	340	5	0	HC
7	32 x 52	7	6	59	WF	S	N–S	W&N	24	260	5	2	HC
9	32 x 56	7	11	34	W	S	E–W	N	24	180	4	0	HC
11	41 x 133	7	11	20	CB	S	E–W	N	60	1,200	24	0	M
13	32 x 98	7	6	13	CB	S	N–S	W	40	160	2	0	M
15	36 x 100	8	5	41	C	C	E–W	N	41	300	4	0	M
17	32 x 72	7	6	25	WF–C	S	N–S	W	28	300	5	2	HC
19	38 x 86	8	6	14	CB	C	E–W	N	40	0	0	0	M
21	34 x 70	7	8	35	WF–C	C	E–W	N	23	400	5	2	HC
23	33 x 97	8	0	39	T	S	E–W	N	32	500	9	2	M
25	34 x 98	8	3	36	C	C–S	N–S	E	34	520	9	2	HC
27	32 x 86	7	6	30	S	S	N–S	E	32	400	10	0	G
29	32 x 100	8	4	40	CB	S	N–S	W	38	330	11	2	M
ABOVEGROUND BARNS													
4	36 x 80	7	10	50	S	------	SW–NW	------	28	350	7	2	HC
6	36 x 100	9	0	18	WF–C	------	NE–SW	------	40	420	6	0	M
8	34 x 52	8	0	23	WF–S	------	E–W	------	16	360	4	2	HC
10	34 x 73	7	9	24	WF–C	------	E–W	------	31	240	3	0	HC
12	32 x 72	7	10	19	S	------	N–S	------	27	400	12	2	HC
14	34 x 52	7	8	18	C–St.	------	N–S	------	18	200	4	0	HC
18	36 x 80	9	10	33	C	------	N–S	------	20	1,000	10	3	M
20	32 x 73	7	10	19	CB–S	------	N–S	------	26	430	6	2	M
22	34 x 112	7	9	19	WF–C	------	E–W	------	48	400	5	0	M
24	32 x 80	7	6	26	WF–C	------	N–S	------	33	260	4	0	HC

[1] S=stone; C=concrete; WF=wood frame with airspace; W=single-boarded; CB=concrete block; St.=steel; T=8-inch tile.

[2] N=north; S=south; E=east; W=west.

[3] M=mechanical; G=gravity; HC=hay and silage chutes.

TABLE 2.—*Number of square feet of floor, wall, and window area, and approximate cubical content (volume) per thousand pounds of weight of animals housed in bank barns and in aboveground barns*

Type of barn and No.	Total weight of animals	Floor area [1]	Wall area [1]	Window area	Cubical content (volume) [2]
	Thousand pounds	*Square feet*	*Square feet*	*Square feet*	*Cubic feet*
Bank barns:					
1	38	68. 2	43. 8	1. 34	511. 5
2	47	49. 8	31. 0	1. 19	368. 5
3	45	54. 7	37. 3	1. 53	404. 8
5	60	49. 0	31. 0	1. 67	357. 7
7	36	38. 7	32. 7	. 90	278. 6
9	35	43. 3	34. 8	1. 29	324. 7
11	100	50. 1	27. 6	2. 50	375. 7
13	54	51. 6	36. 1	4. 72	361. 2
15	57	58. 8	34. 6	1. 42	470. 4
17	41	48. 1	35. 1	1. 95	351. 1
19	52	58. 7	40. 5	4. 37	499. 0
21	35	62. 2	42. 6	2. 29	454. 1
23	51	56. 7	37. 0	1. 47	430. 9
25	53	58. 2	38. 6	1. 64	465. 6
27	52	45. 9	32. 2	1. 54	335. 1
29	60	47. 3	33. 6	1. 20	378. 4
Average	--------	52. 6	35. 5	1. 94	398. 0
Aboveground barns:					
4	43	57. 3	39. 5	1. 16	418. 3
6	54	62. 6	42. 8	3. 50	544. 7
8	25	57. 6	51. 6	2. 00	443. 5
10	43	52. 6	34. 8	2. 23	384. 0
12	47	41. 8	31. 0	2. 21	309. 3
14	27	48. 4	44. 1	2. 78	353. 3
18	36	73. 7	61. 2	2. 14	714. 9
20	40	50. 9	36. 7	3. 00	376. 7
22	67	54. 1	29. 4	2. 88	392. 2
24	46	50. 9	32. 9	1. 96	361. 4
Average	--------	55. 0	40. 4	2. 39	429. 8

[1] Based on inside dimensions.
[2] Based on floor area times mean height between center-service (litter) alley and feed alleys.

MANAGEMENT OF THE TEST BARNS

The investigations were conducted as near as possible under the normal chore procedure of each operator. The time of starting the chores given for the 5 barns in table 3 is typical for all 26 test barns.

Ventilation was probably the most important management factor in this study. Suggestions that would standardize the management of ventilating systems were made to the owners, so that management of similar systems would be comparable in both types of barns. Usually suggestions were to lower the temperature in the barn from

TABLE 3.—*Time of starting various chores in 5 representative test barns*

Barn No.	Chore, and starting time							
	Milking		Cleaning		Feeding hay		Feeding silage	
	a. m.	*p. m.*	*a. m.*	*p. m.*	*a. m.*	*p. m.*	*a. m.*	*p. m.*
3	6:00	6:00	8:30	-------	9:00	5:30	5:45	4:30
4	6:00	6:00	9:00	-------	9:30	7:30	7:30	4:00
15	5:15	5:30	7:30	4:30	8:30	6:45	4:45	4:00
19	5:30	5:30	8:00	4:30	8:30	7:00	5:00	4:00
20	5:30	5:30	8:00	-------	8:30	5:15	6:45	4:30

above 55° F. to between 50° and 55°. This involved opening windows or ducts in nonmechanical systems and changing ventilation controls in mechanical systems. In most instances, the owners followed these suggestions.

PART I.—INVESTIGATIONS OF TEMPERATURE, HUMIDITY, LIGHT INTENSITY, AND ODORS

Investigations of temperature, humidity, light intensity, and odors were mostly a comparison between conditions in stall bank barns (the subject of this study) and stall aboveground barns (the accepted standard).

The investigations of temperature and humidity were conducted in five parts:

(1) Variation in air temperature and humidity in bank barns and in aboveground barns.

(2) Variation in air temperature within barns.

(3) Variation in humidity within barns.

(4) Surface temperature of walls, ceilings, and floors within barns.

(5) Temperature of earth banks.

Variation in Air Temperature and Humidity in Bank Barns and in Aboveground Barns

Measurements of barn air temperature and humidity were made with a standard hygrothermograph equipped with a bourdon tube for detecting temperature and a hair element for detecting relative humidity. One instrument was placed near the center of each barn, with the sensing elements approximately 6 inches below the ceiling joists. In some barns irregularities in the structure made it necessary to place the hygrothermograph a little away from the center. Measurements of air temperature and humidity at different stations within each barn show that the instruments were within an area of maximum barn temperatures in all of the barns.

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A hygrothermograph placed in a centrally located standard type of instrument shelter was used to measure air temperature and humidity outside all barns. Additional weather information was obtained from the United States Weather Bureau, Truax Field Station, Madison, Wis. This station is adjacent to the farm area in which many of the test barns were located.

A total of 502 weekly hygrothermograph records were obtained for the 26 barns during two winter housing seasons and one 2-month period of summer conditions. The number of barns studied in a single week ranged from 5 to 11. Continuous winter records were obtained in four barns. Continuous records were obtained in the other barns for periods ranging from 2 to 6 weeks. Figures 3 and 4 show typical hygrothermograph records for the two types of barns. The records illustrate different ventilating systems. Outside air temperature and humidity is also given.

The hygrothermograph records for temperature and humidity for each week were grouped according to type of barn, and the average weekly temperature and humidity were determined for each type of barn. These averages were then plotted with the corresponding average weekly outside temperature and humidity. Results are shown in figure 5.

There was very little difference in average temperature between the two types of barns. The overall average for the two winter seasons was 54.7° F. for bank barns and 55.7° for aboveground barns. The difference in average relative humidity was small also. The overall average was 67.2 percent for bank barns and 71.8 percent for aboveground barns. The lower average temperature in bank barns more nearly approaches the accepted optimum of 50° (*3*, *5*).[2] The lower average relative humidity in bank barns shows that they were slightly drier than aboveground barns.

In some barns, the average weekly temperature and humidity deviated considerably from the averages shown in figure 5. This difference is attributed to the individual operator, who often used his own comfort rather than the optimum for the cattle as a primary basis for his choice of a comfortable barn temperature.

The weekly pattern of variation in temperature and humidity in each bank barn was compared with the pattern in a similar aboveground barn. The barns were selected for comparison on the basis of size, general construction of exposed walls, arrangement, and population. It was found that each barn had its own pattern of variation in temperature and humidity, due in part to the owner's control of ventilation, but there was no apparent tendency for the patterns in bank barns to be consistently different from the patterns in aboveground barns.

The difference in temperature and humidity between a daytime period (8 a. m. to 6 p. m.) and a nighttime period (8 p. m. to 6 a. m.) was also studied. Results showed very little difference between the two periods. Average temperature was 1° F. lower during the day than during the night, and average relative humidity was 4 percent lower during the day than during the night. The general pattern was the same for the two periods except for the drop in temperature that

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[2] Italic numbers in parentheses refer to Literature Cited, p. 38.

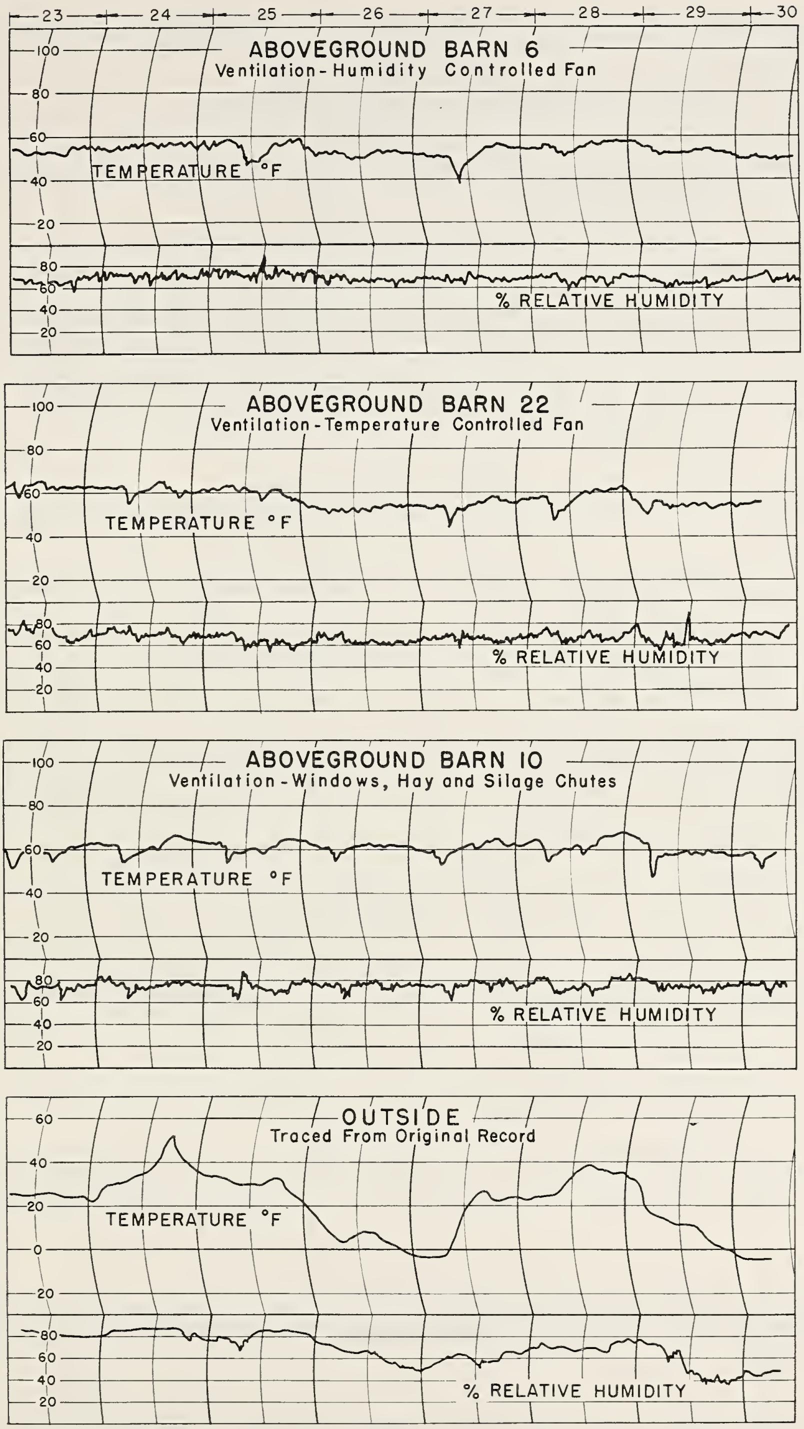


FIGURE 3.—Hygrothermograph records of outside air temperature and relative humidity and of air temperature and relative humidity in aboveground barns 6, 10, and 22 (each with a different ventilating system) during the week of Jan. 23–30, 1950. The sharp drop in barn air temperature before noon indicates when the cows were turned outdoors for exercise.

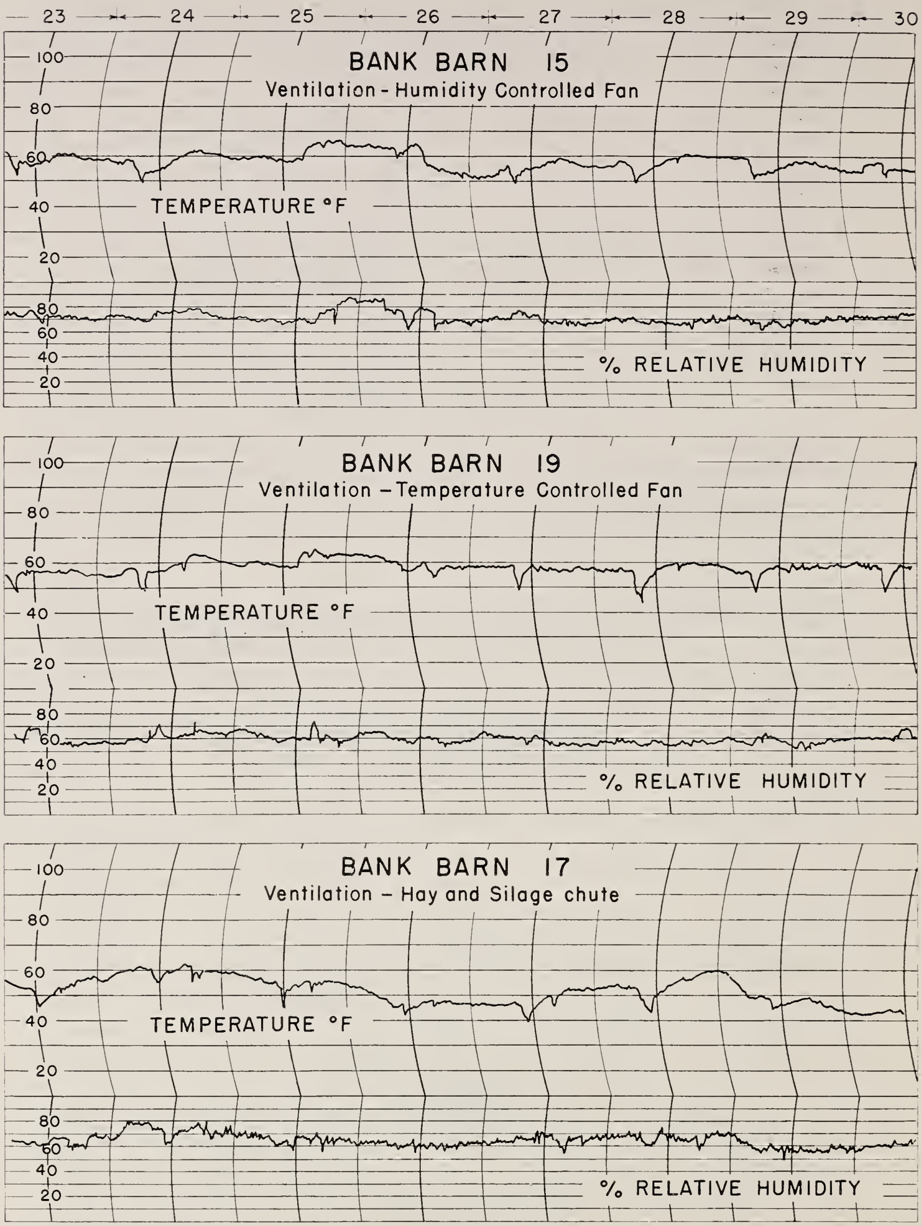


FIGURE 4.—Hygrothermograph records of air temperature and relative humidity in bank barns 15, 17, and 19 (each with a different ventilating system) during the week of Jan. 23–30, 1950. The humidity record for barn 15 is about 4 percent high.

occurred when the cattle were turned outside or when the barn was being cleaned. The size of this drop in temperature varied with the length of time the cows remained outside. In general, after the cows returned to the barn, the rate of recovery for a drop in temperature of 8° was approximately 30 minutes for the first 4° rise and 2 hours for the remaining 4°.

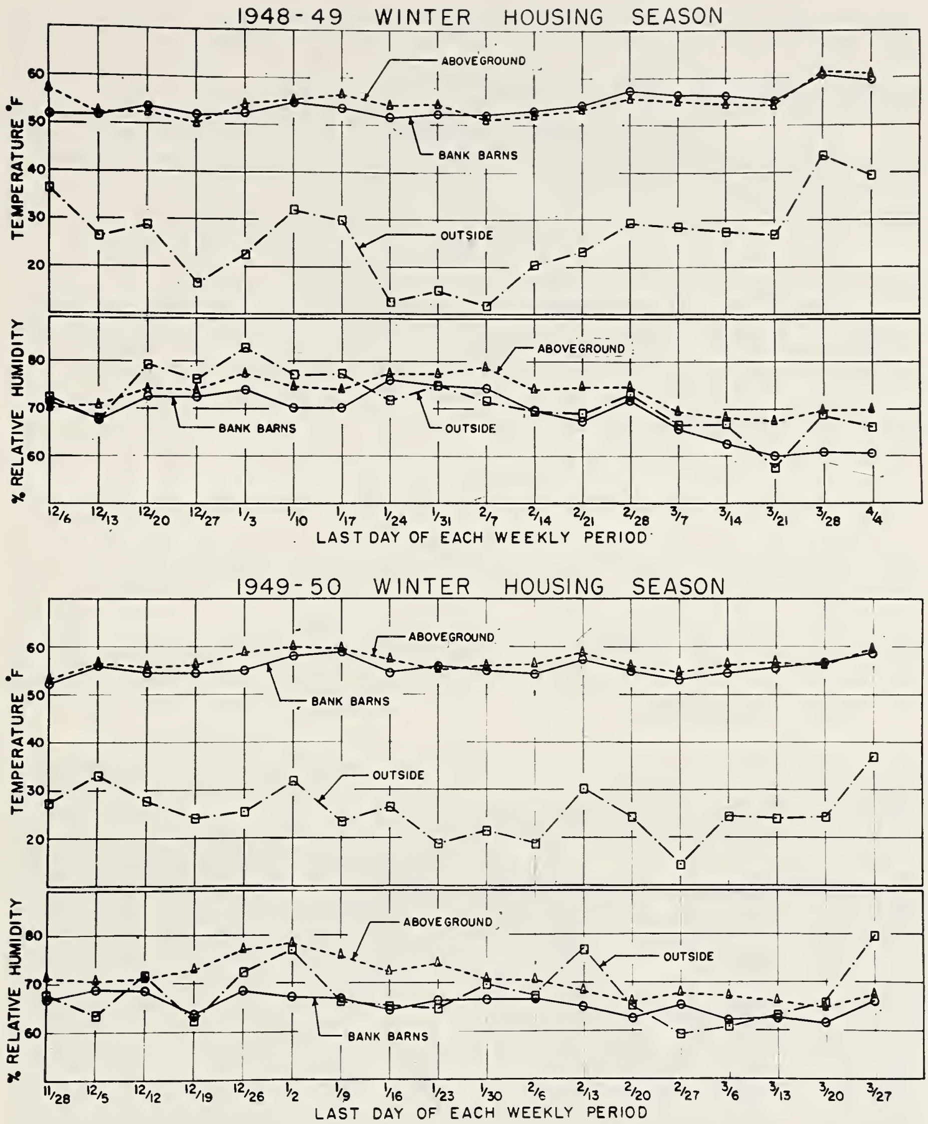
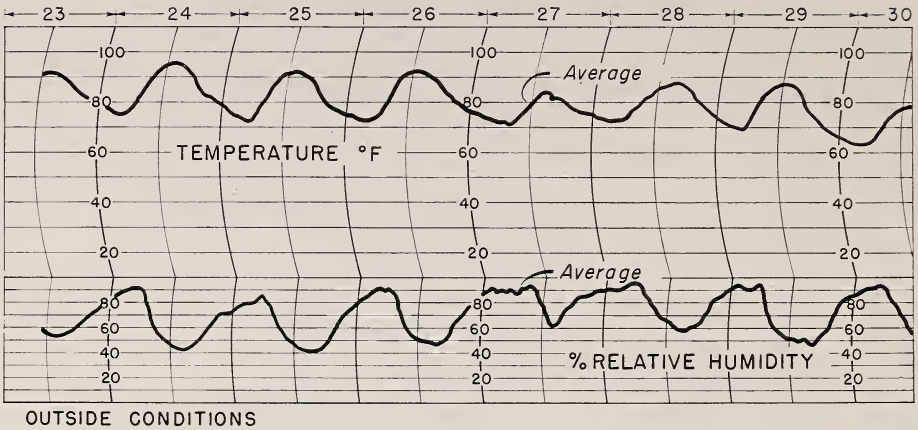


Figure 5.—Average weekly temperature and relative humidity in bank barns and in aboveground barns, and average weekly outside temperature and relative humidity, as determined by hygrothermograph records for several barns, for two winter housing seasons.

Hygrothermograph records for 3 bank barns and for 3 aboveground barns for a 2-month warm-weather period (August and September) were compared by superimposing all records on one chart. The range in temperature during this period was from 45° to 98° F. The cows were in the barns only during the milking period. The comparison showed nearly identical records for all barns of both types, and it was concluded that there was no significant difference in summer conditions within the two types of barns. Figure 6 is typical of the results obtained in the comparison of summer conditions.



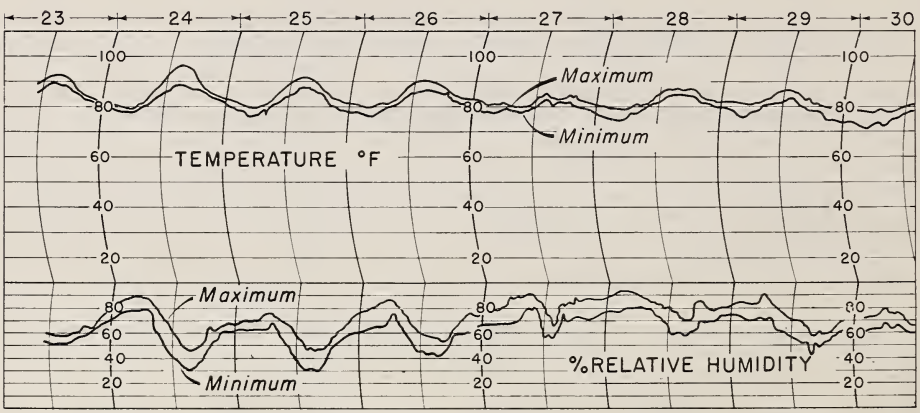


FIGURE 6.—*Upper,* Average outside temperature and relative humidity as determined from hygrothermograph records obtained outside 4 of the test barns, for the week of Aug. 23–30, 1948 (summer conditions); *Lower,* maximum and minimum barn air temperature and relative humidity, Aug. 23–30, 1948, as indicated by superimposing on one chart the hygrothermograph records obtained in bank barns 1, 3, and 11 and in aboveground barns 4, 6, and 10. The hygrothermographs were at a level 6 inches below the ceiling near the center of each barn. In 5 of the 6 barns, the spread between maximum and minimum temperature was 3° F. or less.

Variation in Air Temperature Within Barns

Variation in air temperature within individual barns was measured as a supplement to the hygrothermograph data. These data were compared by type of barn to determine whether or not bank barns differed from aboveground barns in any of the following ways: (1) Variation in temperature at each of several points within the barn; (2) variation in longitudinal temperature (from one end of the barn to the other); (3) variation in lateral temperature (from one side to the other); and (4) variation in vertical temperature (from ceiling to floor).

In each barn, air temperature was measured at from 1 to 5 stations along the center line of each alley, and at stations about 2 feet from the

walls (fig. 2). Measurements were made at 3 levels: (1) 6 inches above the floor (lower or near-floor level); (2) 42 inches above the floor (middle level, or about at the level of the cow's head); and (3) 6 inches below the ceiling joists (upper or near-ceiling level). Some measurements were also obtained between the cows.

Except for barns 6 and 15, discussed in detail below, periodic temperature readings were obtained with a single-point manual balance potentiometer having its copper-constantan thermocouple detecting units mounted on a portable thermocouple stand.

Data were obtained in 10 bank barns and 5 aboveground barns during two winter housing periods at hours that would not interfere with milking and barn-cleaning chores, generally between 10 a. m. and 3 p. m. during the day and between 8 p. m. and 4 a. m. during the night.

A continuous record of the temperature was obtained at each of several points within aboveground barn 6 and bank barn 15. The temperature was measured with a multipoint recording potentiometer that recorded one set of measurements (80 points, some of which represented surface temperature) every 20 minutes. The thermocouple detecting element was shielded from radiation and supported by a thermocouple stand at each of the 3 levels of measurement. (See fig. 7.)

The two barns were representative of the better barns of each type. Both were 36 x 100 feet in size and of 2-story construction. They were of similar arrangement, with 2 rows of cows facing out and with a

FIGURE 7.—Interior of bank barn 15, showing two of the supporting stands for the air-temperature thermocouples of the 16-point recording potentiometer. One extends from the bank to the floor in the center-service (litter) alley, and the other extends from the bank to the floor immediately to the left of the steel posts between the cows.

center-service alley 8 feet wide. Each barn housed 40 Holstein milk cows, 1 bull, and newborn calves up to the age of 6 weeks. The walls of bank barn 15 were monolithic concrete. The walls of aboveground barn 6 were concrete to a height of 36 inches; above the concrete they were wood frame, single-boarded outside and inside and with one thickness of building paper. No insulation was used in the walls of either barn, but the floors of the haymow above the cows were well protected by hay and chaff. More detailed information is given in tables 1 and 2. Exterior views of these two barns are shown in figure 8.

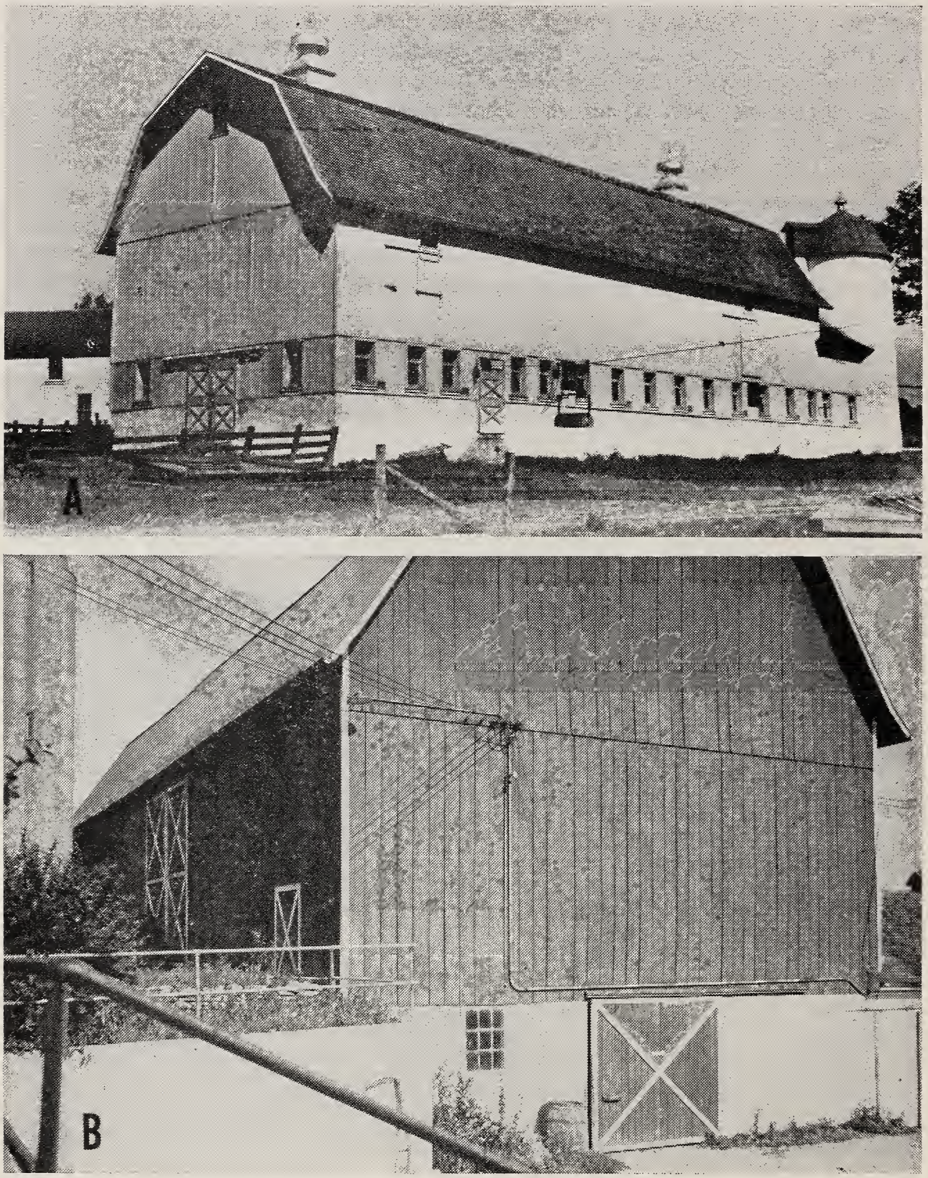


FIGURE 8.—(*A*) Aboveground barn 6 and (*B*) bank barn 15, in which recording potentiometers were installed. The earth bank of barn 15 extends along the full height of the north wall.

Fluctuation in Air Temperature in Barns 6 and 15

Studies of fluctuation in air temperature in aboveground barn 6 and in bank barn 15 showed no difference between the two types of barns that was considered of real significance so far as the health of the cows or the production of clean milk were concerned. Fluctuations were small in both barns. At the upper and middle levels, the temperature changed less than 1° F. per 20-minute interval. This was generally a change incident to a general rise or drop in temperature throughout the barn rather than a fluctuation. At the lower level, there were fluctuations of plus and minus 1°. It should be noted that these measurements were made under conditions of little traffic in and out of the barn and that the thermocouple stations were out of the path of direct drafts of incoming air.

Fluctuation in temperature at points affected by direct drafts of incoming air was too varied to evaluate. However, the drafts were quickly diffused, and they were not very effective more than 3 feet from such sources as cracks around doors and windows unless the cracks were unusually large, such as a missing section of a window light.

Fluctuation in air temperature in relation to surface temperature is discussed on page 20.

Variation in Longitudinal Temperature

Variation in longitudinal temperature was studied in all barns. The degree of variation was different in each barn and could not be associated with type of barn.

The temperature gradation from one end of the barn to the other was very small between points that were 10 feet or more from either end wall (only 1° to 2° F. at the upper and middle levels and 1° to 4° at the lower level). The temperature varied greatly, however, at stations less than 10 feet from the end walls. The temperature at stations 2 feet from the end walls at the near-floor level ranged from 2° to 16.5° below the temperature at stations near the center of the barn at the near-ceiling level. The temperature 2 feet from the end walls at the near-ceiling level was 2° to 10° below the temperature near the center of the barn at the same level. The more extreme differences were attributed to loose-fitting sliding doors along with low outside temperature and wind. The outside temperature was 1° and the wind velocity was 18 miles per hour when the difference of 16.5° was observed.

Variation in Lateral Temperature

Variation in lateral temperature was also studied in all barns. The air temperature varied from one side of the barn to the other in all barns, but the degree of variation was different in each barn. In some barns the lowest temperature occurred along the center-service alley; in other barns, near an exposed wall. At the near-floor level, the difference in temperature across the barn at any one point of cross-sectional measurement was as great as 10° but usually was 6° or less. The difference in lateral temperature at the near-ceiling level was only about half as much as at the near-floor level.

There was a tendency for variation in lateral temperature to differ according to type of barn. When data obtained near the end walls are

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omitted, the average air temperature in bank barns was 1° to 20° F. higher along bank walls than along the opposite exposed walls. In aboveground barns, the average air temperature at comparable levels was approximately the same.

Figure 9 shows the average temperatures in bank barns and in aboveground barns, for two ranges of outside winter temperature.

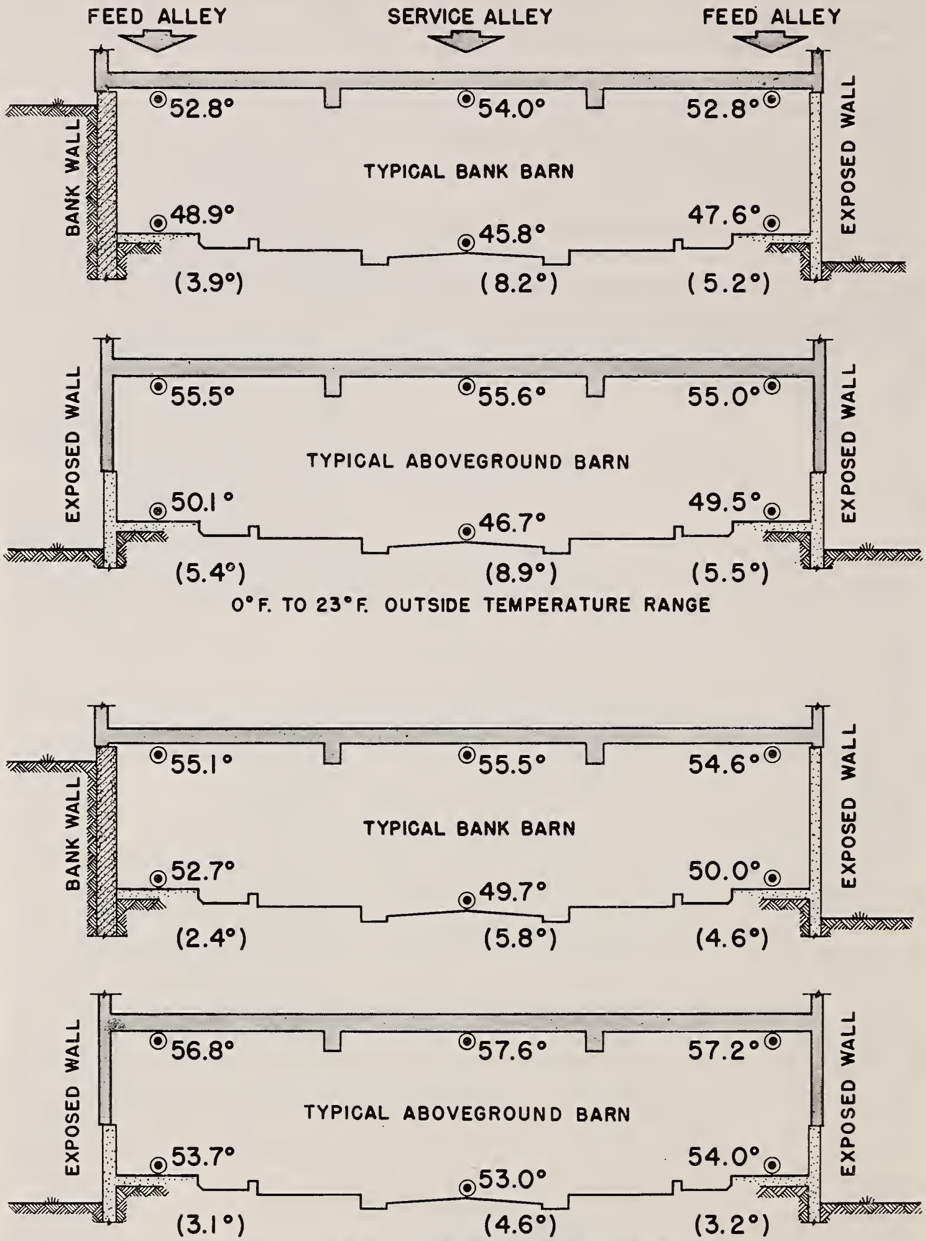

FIGURE 9.—Average temperature in bank barns and in aboveground barns at selected points for two ranges of outside winter temperature. (Average of all data from all barns and along all alleyways within limits of 10 feet from either end wall.) Figures in parentheses indicate difference between the upper and lower levels.

Lateral air temperature at the upper (near-ceiling) level was relatively uniform in both types of barns, when temperatures taken within 10 feet from either end wall or in the direct path of drafts of incoming air are omitted. This was found in all barns studied and indicates that a thermostat-type ventilating fan control could be located anywhere near the ceiling over a wide area within a barn without changing its operational performance (provided, of course, that it is not exposed to direct drafts of incoming air).

Air temperature between the cows at the upper level generally was the same as the temperature at the same level along the center-service alley. At the lower and middle levels, air temperature between the cows was 1° to 9° F. higher than at corresponding levels along the center-service alley, with the greatest difference occurring at the near-floor level. These differences were difficult to evaluate because they varied according to the proximity of the cows to each other and to the thermocouples.

In bank barns there was no noticeable difference in the temperature between the cows that faced bank walls and between the cows that faced exposed walls.

Variation in Vertical Temperature

The air temperature decreased from the ceiling to the floor in all barns, but the difference between levels varied considerably within and between barns. The variability of this difference within barns could generally be associated with outside weather conditions, cold weather causing the greatest vertical temperature gradations between levels. The variability between barns was not associated with any one cause. Differences in the floor plans of the barns, height of ceilings, wall construction, ventilating system, size of herd, and management of the herd were all considered as factors that might affect the differences between barns.

Figure 9 shows the average temperature along the alleyways at the near-ceiling and near-floor levels of bank barns and aboveground barns, for two ranges of outside weather conditions, and the difference between levels. Only small differences could be associated with type of barn. The only difference that was considered of any significance was the smaller temperature gradation (1° to 2° F.) between the upper and lower levels along bank walls than along exposed walls of either type of barn. At other points, the vertical temperature gradation was the same for both types of barns.

The greatest difference in temperature between the upper and lower levels occurred along the center-service alley. This was true for both types of barns and for both ranges of outside temperature, but the difference was appreciably less during warm weather (temperature range 24° to 48° F.) than during colder weather (0° to 23°).

At most measuring stations, the temperature at the middle level (42 inches above the floor) was less than at the upper (near-ceiling) level. However, in both types of barns the difference in temperature between the middle and upper levels was only about one-fourth to one-half as much as the difference between the lower and upper levels.

The general conclusion that was drawn from this study of variation in vertical temperature within barns was that bank barns differ very

little from aboveground barns. The differences that do exist indicate that cattle along bank walls are subject to more uniform temperature than cattle along exposed walls. However, this somewhat greater uniformity in vertical temperature along bank walls did not extend to the area between the cows. The temperature between the cows was similar in both types of barns.

Variation in Humidity Within Barns

A hand-aspirated psychrometer was used to measure relative humidity within barns. Measurements were made at 1 or 2 stations along the center line of the left feed alley, the center-service (litter) alley, and the right feed alley. The stations usually were chosen to represent a cross-section of humidity near the center of the barn. Additional stations were located 2 feet from each end of the center-service alley. Humidity was measured at the same levels as air temperature, as follows: (1) 6 inches above the floor (lower or near-floor level) ; 42 inches above the floor (middle level, or about at the level of the cow's head) ; and (3) 6 inches below the ceiling (upper or near-ceiling level).

Measurements were made when conditions of temperature and air movement were reasonably constant. The time spent obtaining a set of measurements in each barn ranged from 30 minutes to 1½ hours. Some of the first measurements in each set were rechecked after the set was completed. The recheck generally showed a change in relative humidity of less than 5 percent during the measuring period.

Twenty-two sets of measurements were obtained in 8 bank barns and 5 aboveground barns. The data for each set of measurements were plotted as a 3-point curve representing the relative humidity at each level along the left feed alley, the center-service alley, and the right feed alley. These curves showed a wide range of conditions within each barn, with no apparent tendency for the pattern to differ according to type of barn.

Table 4 shows the average, maximum, and minimum temperature and relative humidity at the upper and lower levels along feed alleys, the center-service alley, and the ends of bank barns and aboveground barns, for two ranges of outside weather conditions.

Within areas of uniform temperature, the highest relative humidity in both types of barns occurred along the feed alleys, with the maximum occurring most often at the middle level (42 inches above the floor).

The relative humidity near the end of each barn (2 to 10 feet from the end walls) differed widely from that at corresponding levels of other areas within the barn. In some sets of measurements, the humidity was lower at the end than near the center; in other sets of measurements it was higher.

The general conclusion was that the level of relative humidity is a few percent higher in aboveground barns than in bank barns, but the patterns of cross-sectional relative humidity are otherwise very similar. These patterns change with changes in barn temperature and with changes in the direction and velocity of the wind.

Table 4.—*Variation in relative humidity and temperature between areas within bank barns and within aboveground barns, at 2 levels of measurement and for 2 ranges of outside temperature*

OUTSIDE TEMPERATURE RANGE, 1° TO 20° F.

Level of measurement, type of barn, and area	Maximum		Minimum		Average	
	Relative humidity	Temperature	Relative humidity	Temperature	Relative humidity	Temperature
6 inches below the ceiling:						
Bank barns:	*Percent*	°*F.*	*Percent*	°*F.*	*Percent*	°*F.*
Bank wall feed alley	80	69	69	47	72.8	55.0
Exposed wall feed alley	79	63	63	49	70.5	53.9
Litter alley	76	66	64	50	69.8	55.2
Ends	89	53	64	43	75.8	47.0
Aboveground barns:						
North or west feed alley	85	60	69	44	76.7	53.8
South or east feed alley	86	61	69	44	76.3	54.0
Litter alley	78	63	64	44	70.1	54.7
Ends	85	60	67	40	77.2	51.0
6 inches above the floor:						
Bank barns:						
Bank wall feed alley	82	52	73	43	78.3	47.6
Exposed wall feed alley	85	50	67	42	76.0	46.7
Litter alley	83	50	64	39	73.5	44.1
Ends	79	47	64	35	74.5	41.6
Aboveground barns:						
North or west feed alley	87	57	75	44	82.2	50.4
South or east feed alley	91	57	69	43	80.7	50.1
Litter alley	87	52	66	43	76.5	47.3
Ends	97	49	70	41	80.5	44.4

OUTSIDE TEMPERATURE RANGE, 21° TO 41° F.

Level of measurement, type of barn, and area	Maximum relative humidity	Maximum temperature	Minimum relative humidity	Minimum temperature	Average relative humidity	Average temperature
6 inches below the ceiling:						
Bank barns:						
Bank wall feed alley	74	60	61	51	67.6	56.4
Exposed wall feed alley	77	64	50	55	67.0	56.8
Litter alley	74	62	57	52	65.0	56.8
Ends	77	59	46	50	67.6	55.3
Aboveground barns:						
North or west feed alley	75	59	68	53	72.7	56.0
South or east feed alley	74	59	70	54	72.7	56.3
Litter alley	70	61	62	54	67.3	56.7
Ends	75	59	60	51	69.5	54.8
6 inches above floor level:						
Bank barns:						
Bank wall feed alley	75	59	61	42	70.5	52.9
Exposed wall feed alley	81	58	56	48	71.2	53.4
Litter alley	76	56	61	44	67.5	51.5
Ends	84	53	54	40	69.0	46.9
Aboveground barns:						
North or west feed alley	79	56	70	49	75.0	53.5
South or east feed alley	80	55	74	50	77.3	52.2
Litter alley	82	56	67	45	73.3	50.2
Ends	78	49	64	43	71.0	46.5

Barn Surface Temperature

Inside surface temperature of walls, ceilings, and floors was studied for two principal reasons: (1) To determine the possible benefit of the earth bank as a source of heat in bank barns; and (2) as a part of the dairy cow's environment.

Surface temperature was measured at the same time and at the same levels as air temperature but at a greater number of stations. In barns 6 and 15, surface temperature was measured with a multipoint recording potentiometer. The copper-constantan thermocouple of the potentiometer was imbedded in the wall. In all other barns, measurements were made with a portable pyrometer equipped with a thermocouple detecting element for contact against the surface. The thermocouple junction was placed against but not imbedded in the wall. The junction was of very small wire, approximately 30-gage. Temperatures obtained with the pyrometer checked within 2° F. with temperatures obtained with the potentiometer. The error from this difference is minimized as most data are of a comparative nature.

In the study to determine the possible benefit of the earth bank as a source of heat in bank barns, the surface temperature of bank walls was compared with the barn-air temperature at three levels: (1) 6 inches below the ceiling (upper or near-ceiling level); (2) 42 inches above the floor (middle level, or about at the level of the cow's head); and (3) 6 inches above the floor (lower or near-floor level). Surface temperature was measured at stations approximately 2 feet from air-temperature stations.

Results showed that, under winter housing conditions, the surface temperature of bank walls usually was lower than the barn-air temperature. The difference was about 6° at the near-ceiling level and about 1° at the near-floor level. In some instances, the surface temperature of bank walls was slightly higher (1° to 2°) than the barn-air temperature at the near-floor level, but this condition usually coincided with a drop in barn-air temperature. During short periods (for example, when the cows were let out and the barns were being cleaned), the bank wall was a source of heat.

Figure 10 shows a comparison of wall surface temperature and nearby air temperature in barns 6 and 15, as obtained with the recording potentiometer. The data show that the pattern of surface temperature of bank walls tends to follow the pattern of air temperature, but with some lag. Fluctuations in air temperature of 2° F. were not reflected in the surface temperature of bank walls under normal conditions of air movement over the wall. The tendency for the surface temperature of bank walls to be below the nearby air temperature indicates that heat is lost from the barn to the earth bank. However, the difference between surface temperature and the nearby air temperature is much less for bank walls than for exposed walls; therefore, the heat loss from bank walls is less than from exposed walls.

Floor surface temperature of the stall platforms was very similar for both sides of the barn along both rows of stalls. This was true for both types of barns. In bank barns this similarity shows that the earth bank has little or no effect on the floor surface temperature of the stall platform.

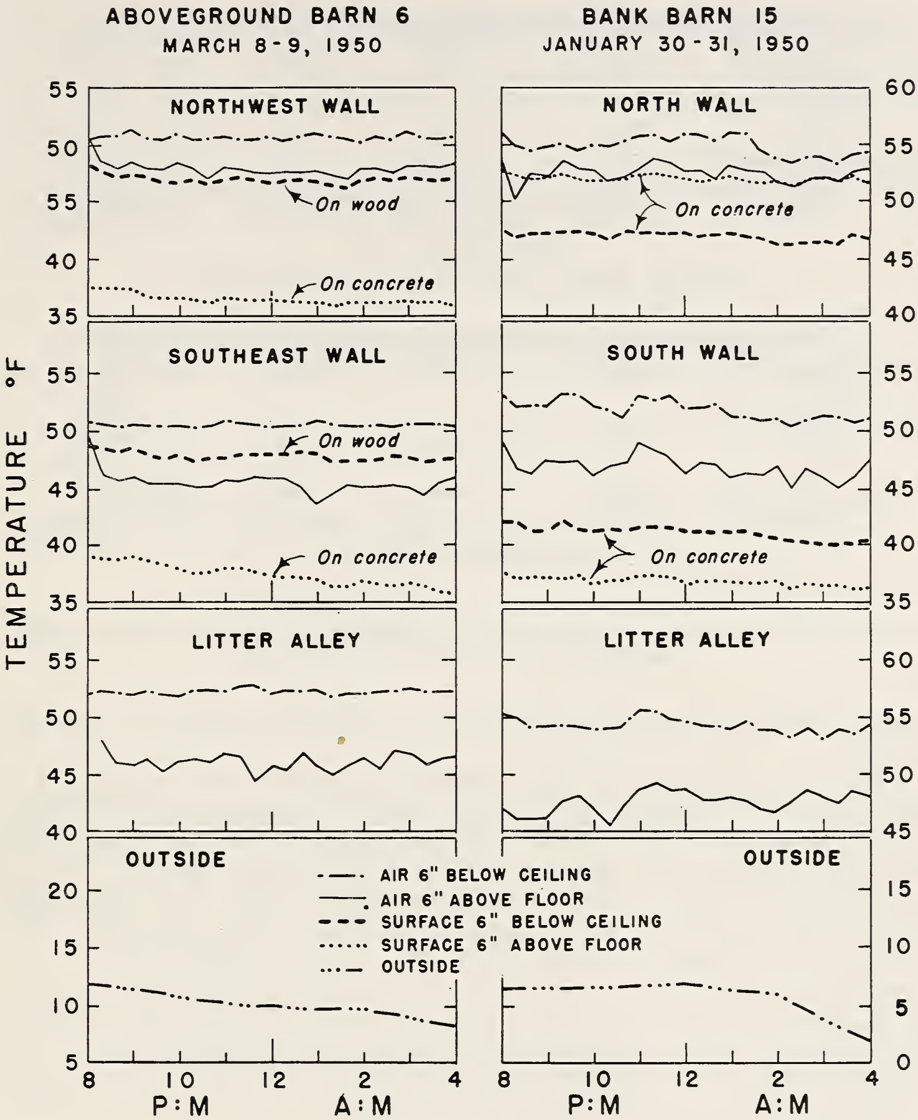

FIGURE 10.—Comparison of wall surface temperature and nearby air temperature at two levels in aboveground barn 6, (March 8–9, 1950), and in bank barn 15 (January 30–31) with corresponding outside temperatures.

Ceiling surface temperature varied primarily according to the air temperature at the near-ceiling level. The insulating quality of the hay stored in the mow above the ceiling minimized the effect of outside temperature.

Figure 11 shows typical surface temperatures for walls, floors, and ceilings and corresponding air temperatures, for bank barn 15 and aboveground barn 6.

Surface temperature was also studied as a part of the animal's environment. A comparison of the data obtained for surface temperature of opposite walls within bank barns shows a wide range of dif-

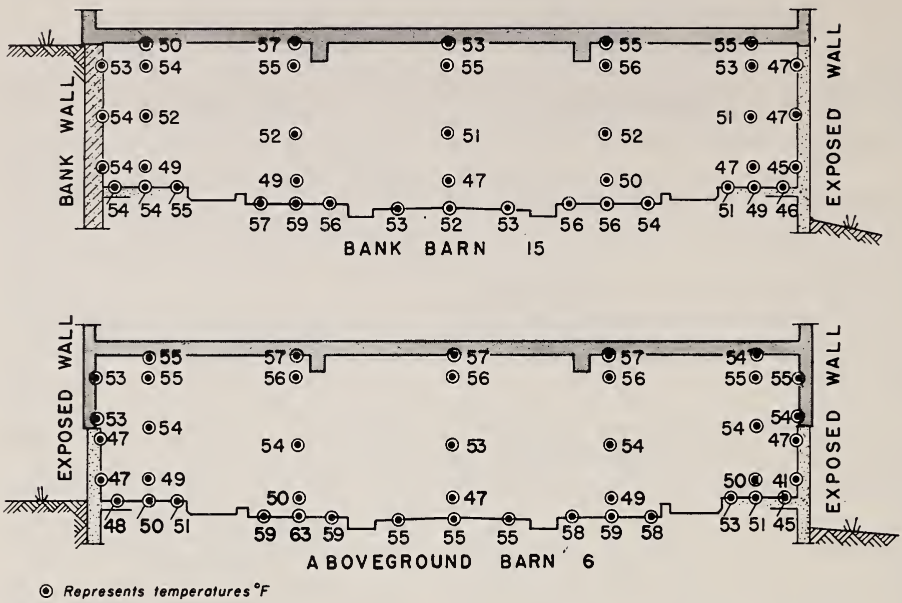

FIGURE 11.—Barn surface temperatures and corresponding air temperatures in bank barn 15 and aboveground barn 6.

ference between the surface temperature of bank walls and of exposed walls.

Surface temperature at the near-ceiling level along the bank wall was from 9° F. higher to 8° lower than at the same level along the opposite exposed wall. These extremes were attributed to differences in wall construction, exposure of bank wall above grade line, and orientation of barn to the sun and prevailing winds. The data show that exposed walls with an estimated coefficient of heat transfer ("U" value) (*l*) of 0.25 B. t. u./sq. ft./hr./°F. temperature difference have practically the same surface temperature as bank walls when the outside temperature is above 30°, and between 0° and 5° lower surface temperature when the outside temperature is from 30° to 0°. If exposed walls were better insulated, the difference between exposed walls and bank walls would be very small.

A comparison of the surface temperature at the near-ceiling and near-floor levels of bank walls with the surface temperature at the same levels of exposed walls shows that bank walls have more uniform temperatures. The surface temperature of bank walls was 0.5° to 2° F. *higher* near the floor than near the ceiling. The surface temperature of exposed walls in both types of barns was 2° to 15° *lower* near the floor than near the ceiling. The greatest difference occurred on exposed walls having concrete for the lower 3 to 4 feet and wood frame above. Barn 6 (fig. 11) provides a good example of the variation in wall surface temperature resulting from different construction materials.

The general conclusions that were drawn from these investigations of surface temperature are: (1) The earth bank reduces the rate of heat loss through a wall, that is, surface temperature along the bank wall is more uniform than along exposed walls; and (2) the earth

bank is a source of heat when there is a drop in barn-air temperature for short periods.

The herdsmen observed no difference between cows along bank walls and cows along exposed walls in either the health of the animals or milk production.

Therefore, it is assumed that the differences in surface temperature observed in these investigations were too small to be of practical significance.

Temperature of the Earth Bank

As part of the study to determine the possible benefit of the earth bank as a source of heat, the temperature of the earth banks along the walls of 6 bank barns was measured at stations from 1 to 75 feet from the walls and at various levels or depths (table 5). All barns were within a radius of 15 miles from Madison, Wis.

Table 5.—*Maximum depth of measuring soil temperature in the earth bank at various distances from the barn wall of 6 bank barns*

Bank barn No.	Distance from barn wall, and maximum depth of measurement					
	1 foot	4 feet	7 feet	13 feet	18 feet	75 feet
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1	84	84	84	84	84	180
2	84	84	84			
11	84	84	55			
13	84	55	55			
15	55					
17	108	84	55			

Waterproofed copper-constantan thermocouples were placed in holes bored with a 2-inch soil auger, at levels 12, 31, 55, 84, 108, 132, 156, and 180 inches below the surface of the ground. The holes were filled at least 2 months before the test period began. The temperatures detected by these thermocouples were measured with a portable, manual balance potentiometer having automatic cold junction compensation.

The soil comprising the earth banks was classed mostly as silt loam with either clay or sandy loam at some levels.

Soil cover consisted of a fairly heavy mat of the summer's accumulation of grass and chaff around the barn. There were varying amounts of snow cover, ranging from none to 2 feet deep. The soil was reasonably moist at all levels, and at lower levels it often was moist enough to adhere to the soil auger rather tightly.

The data show that the temperature at any specific point in the earth bank on any specific date was very nearly the same for all barns. Therefore, the data, when averaged according to date, level of measurement, and distance from the barn wall, are considered representative of all barns in the area.

Table 6 shows the monthly mean temperature of the earth banks for each level and station. These data substantiate the conclusion that although the earth bank is useful as insulation, it is not a significant source of heat. Mean temperatures of more than 50° F. are in boldface, and indicate that these points might possibly supply heat to a barn. A temperature of 50° is considered the optimum barn temperature for stanchioned dairy cattle (*3*,*5*).

TABLE 6.—*Monthly mean soil temperature of the earth banks at each station and level of measurement* [1]

Month, and level of measurement (depth below surface)	Distance of measurement station from barn wall			
	12 feet or more	6 to 7 feet	3 to 4 feet	6 inches to 1 foot
	° *F.*	° *F.*	° *F.*	° *F.*
December 1948:				
84 inches	**54. 8**	**55. 0**	**55. 1**	**55. 8**
55 inches	49. 7	**50. 9**	**51. 4**	**52. 6**
31 inches	43. 9	45. 6	46. 6	48. 7
12 inches	37. 6	39. 5	40. 0	43. 3
January 1949:				
84 inches	**50. 2**	**50. 9**	**50. 9**	**52. 1**
55 inches	45. 1	45. 8	46. 3	48. 6
31 inches	40. 0	40. 1	42. 0	45. 0
12 inches	33. 6	36. 7	36. 5	39. 7
February 1949:				
84 inches	46. 2	47. 9	48. 2	**50. 5**
55 inches	41. 9	43. 5	44. 6	47. 5
31 inches	36. 9	38. 2	40. 3	44. 8
12 inches	32. 4	36. 0	35. 5	40. 7
March 1949:				
84 inches	43. 3	45. 5	46. 8	**50. 0**
55 inches	38. 8	42. 0	44. 3	48. 1
31 inches	35. 2	38. 9	40. 6	46. 4
12 inches	32. 3	35. 0	36. 7	43. 6
December 1949:				
84 inches	**54. 3**	**54. 0**	**53. 5**	**52. 7**
55 inches	49. 4	49. 6	49. 8	49. 6
31 inches	44. 4	45. 2	45. 5	47. 4
12 inches	39. 1	40. 1	40. 8	43. 8
January 1950:				
84 inches	**50. 1**	49. 4	49. 9	49. 7
55 inches	44. 7	44. 6	45. 3	46. 0
31 inches	39. 8	40. 6	40. 8	43. 8
12 inches	34. 1	35. 0	36. 2	40. 8
February 1950:				
84 inches	46. 6	46. 5	47. 2	47. 4
55 inches	41. 4	42. 1	42. 7	43. 6
31 inches	37. 0	37. 7	38. 1	42. 2
12 inches	32. 5	32. 6	33. 9	38. 7
March 1950:				
84 inches	43. 3	44. 6	45. 3	46. 7
55 inches	38. 5	40. 8	41. 6	43. 2
31 inches	34. 8	36. 7	37. 5	43. 3
12 inches	34. 4	34. 3	34. 9	41. 2

[1] Temperatures above 50° (indicated in boldface) indicate possible source of heat to the barn.

Table 6 shows that the earth bank, at depths below 55 inches, might possibly supply heat to the barn in December and January, if the temperature in the barn is 50° or below. The average air temperature in bank barns was approximately 55°, as measured by hygrothermographs in these experiments. Therefore, there was practically no possibility for the earth bank to supply heat to the barns at the near-ceiling level. But the earth bank could supply heat to the barns at the near-floor level where the temperature was 5° to 10° below that recorded at the hygrothermograph stations.

Figure 12 shows the temperature of the earth bank, also surface and air temperature in the barn for a typical bank barn.

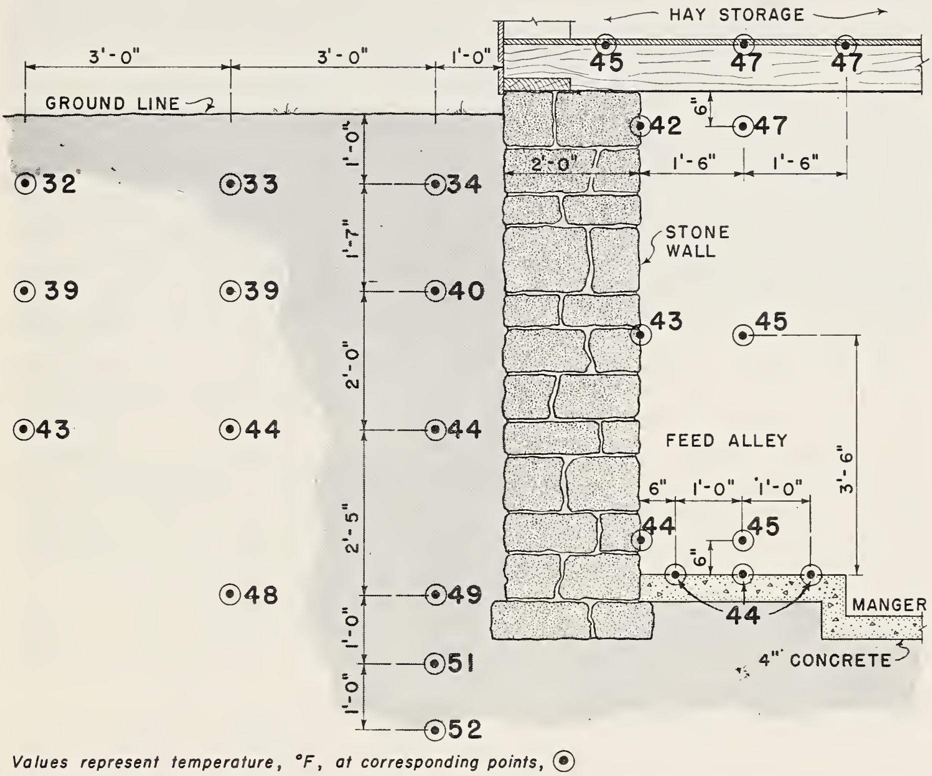

FIGURE 12.—Comparison of the temperature of the earth bank with surface and air temperature in the barn for a typical bank barn.

Table 6 also shows that the temperature of the earth bank at all levels is higher near the wall than at corresponding levels farther from the wall, which indicates that heat is lost from the barn through the wall to the earth bank. The magnitude of this difference increases about 6° between December 1 and March 31 at a level 84 inches below the surface, and about 4° for the same period at a level 12 inches below the surface.

Ground temperature was above freezing to a level 12 inches below the surface during almost the entire test period. This was accounted for by the presence of a good sod, and a cover of dry grass and snow during extremely cold weather. The two winters in which these tests were made were relatively mild.

The general conclusion from these studies of soil temperature was that the earth bank supplies very little heat to a bank barn. On the other hand, the rate of heat loss from the barn through the bank wall is small.

Condensation

Surface condensation in the barns was observed each week when the hygrothermograph charts were changed, and at other times during visits to the farms.

These observations showed that condensation occurs much less frequently on bank walls than on exposed walls. In fact, in the 16 bank barns, condensation was observed on bank walls only twice during the 2 years of these investigations, and then only along the upper portion of the walls. On the other hand, in both bank barns and aboveground barns, exposed walls were very often covered with condensate in cold weather, and in very cold weather this would change to frost. On exposed walls of concrete or concrete block, the accumulation of condensate frequently was great enough to run down the walls and form pools of water on the floor.

Among the 23 barns with a face-out arrangement, condensation was much more prevalent in those with very narrow feed alleys and sweep-in type mangers. This was attributed to the nearness of the cows' muzzles to the wall; the moisture in their breath condensed on the wall.

In general, no condensation was observed on the ceilings of the barns studied. This was attributed to the hay in the mows above being in direct contact with the ceilings. Condensation was observed on the ceilings of some barns (not in this investigation) in which the haymow floor and ceiling were separated by air spaces between the joists. Apparently, drafts of outside air in the joist spaces chilled the ceiling. In one test barn the air duct that was used for drying hay was poorly insulated from the outside and, on cold days, its location could be traced by the condensation it caused on the ceiling.

Driveways to haymows usually were double-planked and covered with 1 inch or more of chaff, and they evidently had good insulating characteristics.

Condensation was observed on bank walls 1 day during the first week of May 1950 when a sudden rise in outside air temperature caused the dew point of the barn air temperature to rise above the surface temperature of the wall. Although none was observed in 1949, owners of bank barns reported that some condensation occurred on bank walls for 1 or 2 days in late spring almost every year. This condition was not considered serious, as it occurred when the cows were outside most of the day and barn doors could be left open for rapid warming of bank walls.

Natural Light Intensity

Obtaining uniform distribution of light in bank barns is an inherent problem because at least one wall is windowless. Natural light intensity was measured in this study (1) to determine the differences between bank barns and aboveground barns in natural light intensity; (2) to appraise the importance of these differences; and (3) to study

FIGURE 13.—Interior view of bank wall in a bank barn. The lack of windows is offset by the whitewashed wall that reflects light well. A clear expanse of wall such as this is easy to keep clean.

possible means of overcoming these differences. Figure 13 shows the inside surface of a typical windowless bank wall in a bank barn.

So far as is known, light is important primarily in providing sufficient light for the proper performance of chore operations and in providing a pleasant working area which serves as a stimulus for the farmer to do a better job in caring for his livestock, barn, and equipment. Other benefits have been suggested but have not been proved satisfactorily.

Natural light intensity was measured in 5 bank barns and in 7 aboveground barns under various solar and sky conditions. Measurements were obtained (in terms of foot-candles) with either a single-cell lightmeter (with ranges of 0–100 foot-candles and 0–1,000 foot-candles) or a 4-cell lightmeter (with ranges of 0–3.5 foot-candles and 0–35 foot-candles). The light cell was held in a plane parallel to the floor at levels 3 inches and 24 inches above the floor. Measurement stations were at intervals of 5 feet along the center of each alleyway. All barns were whitewashed annually, except barn 19. It was painted white every 3 years.

Variation in Natural Light Intensity Along Alleyways

The least uniform distribution of light was found along feed alleys that received direct sunlight through the windows. In some sets of measurements, light intensity at each level ranged from 4 foot-candles (along sections of the wall where there were no windows because of an attached silo, milkhouse, etc.) to 1,000 foot-candles (where measure-

ments were made in the direct rays of the sun). Uniform distribution of window area resulted in more uniform distribution of light in the alleys.

Light intensity was more uniform along center-service (litter) alleys and along feed alleys near bank walls and shaded walls than along feed alleys that received direct sunlight through the windows. In fact, there was very little variation in light intensity along these alleyways except near pens, empty stalls, cross alleyways, or at times when the sun was low enough in the sky so direct rays of sunlight reached the center-service alley. Along center-service alleys and shaded feed alleys, the difference in light intensity between the 2 levels was very small, often 3 foot-candles or less.

Feed alleys were noticeably dark where readings of 0.5 foot-candle were obtained, but there was enough light to distinguish bits of hay on the rather dark concrete floors. Higher readings were obtained where there were windows in the walls at each end of the feed alleys, particularly in the early morning or late afternoon in barns with an east-west orientation of their long axis.

Light intensity along the center-service alley in bank barns was an average of light intensity along the two feed alleys. In aboveground barns, light intensity along the center-service alley usually was lower than along the feed alleys. As a result, light intensity along the center-service alley often was the same in both types of barns. The range of light intensity usually was between 2 and 10 foot-candles along the center-service alley at a level 3 inches above the floor between 8 a. m. and 4 p. m., when the cows were in their stanchions. Some of the cows were in a standing position and some were lying down.

Variation in Natural Light Intensity Between Alleyways

Variation in natural light intensity between alleyways was compared by grouping data from all barns according to the time of day the measurement was taken; the sky cover, expressed in tenths of total possible; and the season, insofar as it concerned the angle of the sun's rays with the earth. This comparison showed that variation in natural light intensity between alleys was greater in bank barns than in aboveground barns, with the greatest difference between feed alleys. This was expected, as light is admitted to bank barns from only three sides. However, considerable variation in light distribution was also found in aboveground barns, particularly in those with the long axis running east and west.

Generally, light intensity along the exposed wall in bank barns was equal to or higher than along the walls of aboveground barns having the same orientation. This resulted from a greater concentration of glass area on the one exposed side wall in bank barns. Light intensity along bank walls was relatively low. Range of light intensity usually was between 0.5 and 15 foot-candles along north bank walls at a level 3 inches above the floor between 8 a. m. and 4 p. m., whereas along north walls of aboveground barns having the same orientation as the bank barns, the range usually was between 1.5 and 25 foot-candles.

In bank barns, light intensity was lower along east and west bank walls than along north bank walls. Barns with south bank walls are said to have been built, but none were located for this study. It is

assumed that barns with south bank walls would be exceptionally dark.

General Level of Light Intensity

The general level of light intensity within barns was higher in aboveground barns than in bank barns. Most of the aboveground barns had greater window area than bank barns—1 square foot of glass per 15 to 25 square feet of floor area in aboveground barns as compared with 1 square foot of glass per 20 to 40 square feet of floor area in bank barns. Measurements of light intensity in four of the test barns are shown in table 7.

Factors that affected natural light intensity within barns were location and size of windows; height of ceiling; obstruction of light by dirt, condensation, and frost on the windows, adjacent buildings, and interior projections such as ceiling beams; reflectivity of the walls; and orientation of the building.

Poor spacing of windows caused dark areas in the barn (at least dark by comparison with the other areas). Low windows contributed to poor illumination near the center of the barn, as did low ceilings and deep beams.

Dirt and condensation on the windows did not cut down light intensity in the barn seriously, but frost on the windows cut down light intensity throughout the barn by more than 50 percent. Obstruction of light by adjacent buildings, such as silos, reduced the effectiveness of the windows by a similar amount.

The effect on light intensity of whitewash or white paint was not measured. However, the importance of good reflective surfaces was apparent from observation. For example, small articles could be distinguished with greater ease along bank walls after they were whitewashed.

The effect of orientation on light intensity along the center-service alley was not readily apparent, but an east-west orientation of the long axis of the barn did result in greater differences in natural light intensity between alleyways.

If bank barns were built according to recommended construction practice with 4 square feet of glass area per cow (*4*), a large percentage of the area of the exposed walls would be glass. Although this was found to be structurally possible, there was some question as to the effect this seemingly unbalanced distribution of glass area might have on the cows and on working conditions in the barn. To study this question, bank barn 19 was remodeled. Fixed double-glass windows were built into the south (exposed) side wall. They provided 160 square feet of insulated glass (2 sheets of 3/16-inch crystal glass separated by a ½-inch airspace). In addition, there were windows in the end walls at the ends of the feed alleys. Total window space was a little over 4 square feet per animal. Figure 14 is an exterior view of the barn.

Results showed that good lighting was obtained throughout the barn. The windows in the end walls at the ends of the feed alley were very useful in providing early morning and later afternoon light along the bank wall. With outside light intensity as low as 350 foot-candles, there was sufficient light for the herdsman to perform all barn chores without the aid of artificial light.

TABLE 7.—*Average midday light intensity (foot-candles) in 4 of the test barns, at 2 levels of measurement* [1]

Place of measurement	Barn, and level of measurement							
	Aboveground barn 6		Aboveground barn 10		Bank barn 15		Bank barn 19	
	3 inches above floor	24 inches above floor	3 inches above floor	24 inches above floor	3 inches above floor	24 inches above floor	3 inches above floor	24 inches above floor
South feed alley:	*Ft.-c*	*Ft.-c*	*Ft.-c*	*Ft.-c*	*Ft.-c*	*Ft.-c*	*Ft.-c*	*Ft.-c*
At windows	100	120	55	250	[3] 1,000	250	[3] 1,000	245
Between windows	[2] 200	120	45	55	14	19	45	60
At ends	100	110	----------	----------	1	1	15	26
Center alley:								
At windows	8	9	8	7	6	5	9	12
Between windows	6	8	6	5	4	6	9	13
At ends	7	9	5	6	2	1	6	7
North feed alley:								
At windows	9	16	11	25	2	3	5	8
Between windows	9	13	9	16	2	3	3	5
At ends	7	12	----------	----------	5	18	4	20
Square feet of floor area per square feet of window area (number)	18		24		41		14	

[1] See tables 1 and 2 for description of barns. Distribution of light was uniform along both south and north sides of aboveground barns 6 and 10; practically all glass area was concentrated on the south side of bank barns 15 and 19. Measurements were made between 11 a. m. and 12:30 p. m. in February, April, and May 1950; the sky was clear.

[2] Higher light intensity between windows due to slight angle of long axis of barn to true west.

[3] Light meter in direct rays of sun; 1,000 was upper limit of meter scale.

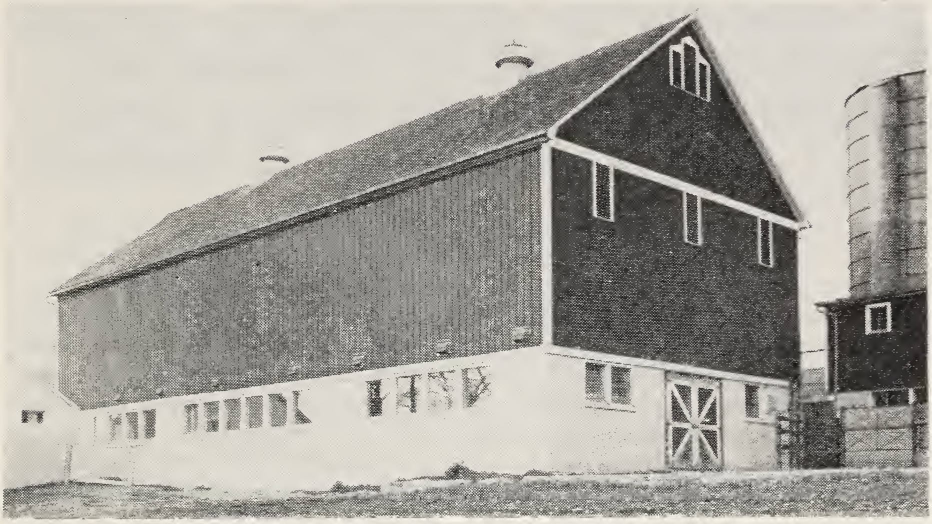

FIGURE 14.—Bank barn 19, with double-glass area of 4 square feet per animal in the south wall.

Purebred Holstein cows housed in the barn had excellent production records, and no ill effects on the cattle from this concentration of glass area on one side of the barn were observed during the 2 years of the test. It should be noted that mechanical ventilation was necessary because the 160 square feet of glass area was fixed.

The temperature along the exposed walls was only a very little lower than along the bank wall. Often the difference in temperature was less than 1° F. The fixed double-glass windows undoubtedly contributed to this uniformity of temperature. Loss of heat from the barn was decreased, which permitted a greater number of air changes within the barn and resulted in a low relative humidity (60 percent) and a temperature of less than 55° when the outside temperature was 30° or lower.

The relation between the time of doing the various barn chores and the amount of natural light available was also studied. Results show that morning and evening milking is done during the hours of darkness for the greater part of the winter housing season. Morning silage feeding on many farms and evening hay feeding on practically all farms require the use of artificial light. Cleaning of gutters and alleyways, and brushing the cows are definitely done during daylight hours.

It was concluded that the difference in natural light intensity between bank barns and aboveground barns is not a serious problem. The lower overall average light intensity in bank barns can be overcome by placing most of the required window area in the wall opposite the earth bank, with a window in the end walls at each end of the feed alley along the bank wall. Bank walls should have a good light reflecting surface.

Although overall light intensity is lower and distribution of light across the barn is less uniform in bank barns than in aboveground barns, light intensity along the center-service alley in barns with a face-out arrangement is very nearly the same in both types of barns.

Chores such as milking (often a daylight chore in the summertime), grooming the cattle, cleaning gutters, and bedding the cattle are performed in this area. The cattle are apparently unaffected by the lack of uniformity in light distribution. In building new barns or in remodeling old bank barns, it is important to keep south walls and other windowed areas free from silos or any other buildings that might obstruct light.

Odors

Barn odors have been suspected of causing off-flavors in milk. They cause disagreeable working conditions, and they leave an undesirable impression with consumers who have occasion to visit the barns.

Work by Trout and McMillan (*7*) and Russell (*6*) indicate that direct absorption of odors by milk is not a problem for the short time that the milk is exposed to such odors if recommended standards for handling milk are followed. However, Babcock's experiments with absorption of the odor of garlic (*2*) showed that odors can cause off-flavors indirectly, through the cow's body.

In these studies, organoleptical observations of odor were made in all test barns and in some other barns. No exact value was attributed to the intensity of the odors, but in all barns they were imparted to clothing in half an hour or less. No significant differences were noted between bank barns and aboveground barns.

A study of rejections of milk at dairy plants, made in connection with the study of milk quality in Part II of these investigations, showed very few rejections because of odors—6 out of an estimated 15,000 cans of milk from bank barns (1 of these also contained bloody milk) and 4 out of an estimated 20,000 cans of milk from aboveground barns. This low percentage of rejections, and the possibility that the barn might not have caused the odors, indicates that odors are not any more of a problem in bank barns than in aboveground barns.

It was concluded from these observations that odors persist in both types of barns, but the odors do not affect the quality of the milk when it is produced according to recommended standards of handling milk.

Water Seepage Through Bank Walls

Water seepage from the earth bank through bank walls was not a serious problem. Water seepage occurred in only about 20 out of approximately 300 bank barns visited in the process of choosing barns for this study. The cause in these 20 barns was either a badly cracked wall or the result of surface drainage against the bank wall aggravated by holes dug by rodents.

Cracks are a hazard in any wall, but they can be minimized by proper construction. It was noted, however, that bank walls of masonry construction were in better condition than exposed walls of the same material.

In all cases, seepage caused by surface drainage was corrected when the earth bank was graded to provide good drainage away from the wall. Waterproofing bank walls before backfilling and placing drain tile at the footing line provide additional insurance against seepage through bank walls.

PART II.—STATISTICAL COMPARISON OF THE QUALITY OF MILK PRODUCED IN BANK BARNS AND IN ABOVEGROUND BARNS

The quality of milk produced has long been considered an important measure of various dairy-cattle housing practices. Because the bacterial content of milk is the usual measure of quality, it was decided to compare the bacterial content of milk produced in bank barns and in aboveground barns. Although the sediment content of milk is largely a measure of the care exercised in handling the milk, the sediment content was determined as a possible indication of the influence of barn conditions on the chore habits of the dairyman. Some attention was also given to the bacterial content of the air in both types of barns.

Sampling Procedure

The barns used in the study of milk quality were chosen from farms furnishing milk to Madison, Wis., dairies. The routes of 13 milk truckers were chosen at random, and all barns served by these truckers were visited and classified as to type, construction, and plan.

Barns with more than 50 percent of one side wall built into an earth bank were classified as bank barns. Some barns also had parts of their end walls built into the earth bank. All of these barns had enough earth against one major wall to cause an appreciable reduction in window area along that side. Of the 202 barns visited, 119 were classified as aboveground barns and 83 were classified as bank barns.

The Division of Milk Sanitation of the City of Madison Health Department made the determinations of bacterial content and sediment content of the milk as received at the dairy plants.

The standard methylene-blue test was used to determine the bacterial content of milk delivered between January 1, 1948 and March 31, 1949. With this test, values of 5 or more were considered acceptable for milk that was to be pasteurized for human consumption. Values below 5 were considered low enough for rejection. The bacterial plate count method, instead of the methylene-blue test, was used to determine the bacterial content of milk samples for the period April 1, 1949 to April 1, 1950. A bacterial count of 50,000 or less in the raw milk was considered satisfactory for milk for human consumption without pasteurization, and a bacterial count up to 200,000 in the raw milk was considered satisfactory for milk that was to be pasteurized.

The sediment content of the milk samples was determined, and the samples were graded numerically from 1 to 4. Grade 1 indicated that the sample was practically free of sediment; grade 2 indicated a small amount of sediment; grade 3 was considered a high sediment count but acceptable; and grade 4 was considered sufficiently high for rejection.

Statistical Analysis

The maximum, the minimum, and the average bacterial content and sediment content of milk samples were determined for each barn, and the results were then averaged according to type of barn. The statistical service of the College of Agriculture, University of Wisconsin, analyzed the results.

Data for the period January 1, 1948 to March 31, 1949 (when the methylene-blue test was used to determine the bacterial content of the milk) were analyzed in two parts. The first analysis included data for the calendar year 1948; the second analysis included data for the 5-month winter housing period of November 1, 1948 to March 31, 1949. Results are shown in table 8.

TABLE 8.—*Comparison between bank barns and aboveground barns in quality of milk produced, as determined by methylene-blue and sediment tests, for the calendar year 1948 and for the winter housing period (Nov. 1, 1948 through Mar. 31, 1949)*

Test period, and type of barns	Methylene-blue test			Sediment test		
	Maximum	Minimum	Average [1]	Maximum	Minimum	Average [1]
Calendar year 1948:						
Bank barns	7. 94	5. 84	7. 15	2. 91	1. 62	2. 21
Aboveground barns	7. 91	6. 04	7. 14	2. 91	1. 49	2. 14
Winter housing period:						
Bank barns	6. 96	6. 59	6. 79	2. 29	1. 74	2. 03
Aboveground barns	6. 99	6. 54	6. 87	2. 35	1. 68	2. 02

[1] Based on corresponding maximum and minimum values of individual barns

Milk produced in bank barns differed very little from milk produced in aboveground barns in average bacterial content and average sediment content, sometimes favoring one type of barn and sometimes the other. None of the differences were significant.

Data for the period April 1, 1949 to April 1, 1950 were also divided for analysis. Data for April 1 to November 1, 1949 represent the summer season when the cows are brought into the barn for milking only; data for November 1, 1949 to April 1, 1950 represent the winter housing season. The data for each season were analyzed as follows: (1) Comparison between the two types of barns; (2) comparison between the variability among samples within bank barns and within aboveground barns; and (3) comparison between the variability among bank barns and among aboveground barns. No significant differences were found in any of these comparisons.

For both types of barns, the variation between samples was considerably greater and the average bacterial content was higher during the summer months than during the winter months. This was attributed in part to better milk cooling during the winter, as about 80 percent of the barns surveyed used well water for cooling milk.

Bacterial Content of Barn Air

The bacterial content of the air in bank barns and in aboveground barns was compared by the simple method of exposure of open agar plates for specified periods. Results of the comparison are shown in table 9. It is realized that the bacterial content of milk is not altered significantly by exposure to barn air under normal conditions and that other sources of bacterial contamination would be of so much greater importance that they would probably completely overshadow the effect of the barn air on milk quality.

TABLE 9.—*Comparison of average bacterial content of air in bank barns and in aboveground barns* [1]

Barns compared [2]	Tests	Time plates were exposed	Average bacterial count	
			Bank barns	Aboveground barns
	Number	*Minutes*	*Number*	*Number*
Barns 3 and 4	1	5	205	388
Barns 5 and 6	3	5	333	283
		5	380	336
		2	209	185
Barns 7 and 8	2	2	152	182
		1	144	182
Barns 9 and 10	2	1	128	111
		1	185	157
Barns 1 and 10	2	1	233	111
		1	235	157

[1] Each test is based on an average count of bacteria on 5 to 8 plates exposed at floor level at various stations, with the cattle in the barn.
[2] Odd numbers are bank barns; even numbers, aboveground barns.

Interpretation of Findings

There were no significant differences in quality, as determined by bacterial and sediment content, between the milk produced in bank barns and the milk produced in aboveground barns. It was concluded, therefore, that any differences between the two types of barns would have no appreciable effect on the bacterial content or on the sediment content of milk produced in either type of barn.

SUMMARY AND CONCLUSIONS

These investigations show that bank barns are acceptable for housing dairy cattle and for the production of high-quality milk. These conclusions are based on a comparison of temperature, humidity, light intensity, and odor in 16 bank barns and 10 aboveground barns, and a statistical comparison of the quality of milk produced in 83 bank barns and 119 aboveground barns. The findings are summarized in the following paragraphs:

1. The weekly average air temperature and the weekly average relative humidity were slightly better for animals in bank barns than in aboveground barns during the winter housing season. During the summer months, temperature and humidity in the two types of barns were very much alike.

2. There was very little difference between the patterns of variation in air temperature and humidity within bank barns and within aboveground barns. However, temperature and humidity were slightly more uniform along bank walls than along exposed walls in either type of barn.

3. When the temperature in the barn was above 50° F., the earth bank did not supply heat to bank barns; in fact, heat was lost through the bank wall to the earth bank. However, at times of rapidly falling barn temperature, the earth bank became a source of heat.

4. The insulating qualities of bank walls constructed of masonry were sufficient to permit satisfactory ventilation and to maintain optimum barn temperature even during short spells of extremely cold weather.

5. Condensation was not observed on the ceilings of test barns, as they were protected with a covering of hay or bedding on the mow floors.

6. Condensation seldom occurred on bank walls during cold weather. Condensation occurred on bank walls during warm weather once or twice a year at times of a sudden rise in outdoor temperature and relative humidity.

7. Condensation occurred frequently on exposed walls in both types of barns during freezing weather, and single-glass windows were covered with frost. However, condensation on exposed walls did not cause the bacterial count of milk to rise above the limit for grade A pasteurized milk.

8. Light intensity was less uniform and generally was lower in bank barns than in aboveground barns, because bank barns had about 20 percent less window area than aboveground barns. Along the center-service (litter) alley—an important work area from the standpoint of quality milk production—light intensity was similar in both types of barns.

9. Concentration of 4 square feet of glass area per cow along the south wall of a bank barn built with its long axis east and west was satisfactory for general lighting and herd health.

10. No significant differences in odors were found in the two types of barns. A study of dairy-plant records showed very few rejections of milk because of odors.

11. No significant differences were found in the quality of milk produced in the two types of barns.

SOME CONSIDERATIONS FOR THE DESIGN AND PLANNING OF STALL BARNS FOR DAIRY COWS

Both bank barns and aboveground barns are best with a center-service alley arrangement, and with the cows facing out.—Past studies indicate that the center-service alley is more efficient from the standpoint of milking, cleaning the barn, and care of the cattle. The studies showed that distribution of natural light is better for milking and gutter-cleaning operations with face-out arrangement. The manure splatter on walls with face-in arrangement presents a sanitation problem in both types of barns.

Comments Regarding Bank Barns

Pens and stalls should be protected from drafts caused by open doors.—Pens and stalls that are located near doors, particularly the large doors to the cow yard, may be subject to objectionable drafts and sudden changes of temperature.

Shade windows in summer.—Protection of south and west windows from summer sun will contribute to lower barn temperatures.

Bank walls have low heat loss.—The average temperature of bank walls is more uniform and higher than the average temperature of exposed walls. This contributes to better ventilation.

Bank barns are well adapted to building sites with a south slope.—Bank barns are best when built with the long axis east and west, the north wall in the bank, and the south wall exposed to provide maximum natural lighting. Second choice would be to build with the long axis north and south and the west wall in the bank.

Bank barns provide ground-level approach to the second floor.—This feature makes the second floor more convenient for feed storage, livestock housing, or other uses.

Bank walls of concrete provide durable and economical construction.—Poured (monolithic) concrete is best for bank walls. To insure a dry wall, drain tile should be placed at the footing line and the concrete surface next to the earth should be waterproofed before back filling. Surface drainage should always be away from the barn.

For good natural lighting of bank barns, south walls should be fully exposed to the sun.—South walls of bank barns should not have other structures, such as silos or milkhouses, against them so as to obstruct light. Four square feet or more of glass area per cow can then be provided in the south wall. When the site permits, windows in the east and west end walls at the end of the feed alley along the bank wall are desirable.

Comments Regarding Aboveground Barns

Aboveground barns are adapted to more flexible farmstead planning.—Level sites permit varied orientation and a wide choice in the location of the barn, which may contribute to better farmstead arrangement.

Aboveground barns permit wider selection of building materials and type of construction.—Although concrete is best for barn foundations, wood, masonry, metal, or composition materials may be used for first-floor wall construction, depending on the owner's preferences, design features, cost and availability of materials.

More uniform natural lighting is possible in aboveground barns.—Most uniform lighting is obtained when the barn is built with the long axis north and south. Choice of north and south or east and west axis will depend on farmstead arrangement and on the relation of the cowyard to the barn. Good natural lighting can be obtained with either orientation when windows are properly spaced.

Aboveground barns usually provide better summer ventilation.—Windows placed in all four walls provide cross ventilation.

Shade windows in summer.—Protection of south and west windows from summer sun will contribute to lower barn temperature.

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